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Research brief

Estimates of CO₂ fluxes for Cape Town

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Nickless et al. (2018) recently provided the results of an atmospheric inversion carried out for the city of Cape Town with the objective of obtaining estimates of weekly CO₂ fluxes at a spatial resolution of 1 km × 1 km. This approach incorporates the best information available on what the fluxes are believed to be from anthropogenic and natural sources, together with estimates of the uncertainty around these estimates, and uses measurements of CO₂ concentrations to improve on these estimates. CO₂ concentrations were measured, by means of Picarro Cavity Ring-down Spectroscopy (CRDS) analysers, from March 2012 until July 2013 at Robben Island and Hanglip lighthouses. These measurements allow the inversion to correct the prior estimates of the fluxes. The CO₂ fluxes can be converted into CO₂ concentrations by means of an atmospheric transport model – the inversion attempts to improve these modelled concentrations. Measurements at the Cape Point Global Atmospheric Watch Station were used to estimate the background CO₂ concentration.

The atmospheric transport model makes it possible to create a sensitivity matrix which converts the fluxes into concentrations at a location at a particular point in time. For this study a Lagrangian Particle Dispersion Model was used as the transport model, driven by climate inputs from the CCAM (Conformal Cubic Atmospheric Model) regional climate model in stretched grid mode (Engelbrecht et al 2013), zoomed in over Cape Town.

The prior information is key to performing a successful atmospheric inversion. To obtain prior estimates of the anthropogenic emissions, a spatially and temporally disaggregated inventory analysis was performed for Cape Town (Nickless et al. 2015). For each grid cell in our domain of interest, the direct emissions of anthropogenic CO₂ needed to be estimated. The sources considered were road vehicle emissions, domestic emissions from lighting and heating (not indirect emissions from electricity usage), airport and harbour emissions, and industrial point sources (which included power stations located within the domain). Emission factors reported by the IPCC and DEFRA, UK, were used to convert fuel use and other activity data into emissions. Error propagation techniques were used to obtain uncertainty estimates, and these ranged between 6.7% to 71.7% of fossil fuel flux estimate.

Natural fluxes over land were obtained from a land-atmosphere exchange model – CABLE (Community Atmosphere Biosphere

Land Exchange model). This model can be used to calculate the fluxes of momentum, energy, water and carbon between the land surface and the atmosphere, based on process models of the major biogeochemical cycles of the land ecosystem. CABLE was dynamically coupled to CCAM, which meant that feedback between the climate and the biosphere could be explicitly modelled, instead of the land-atmosphere exchange model only reacting to the climate inputs. The net primary productivity was used as an estimate of the uncertainty around the net ecosystem exchange flux, therefore these uncertainty estimates were large relative to the nett natural fluxes. This meant that the atmospheric inversion was able make relatively larger corrections to the natural fluxes than to the anthropogenic fluxes. Ocean fluxes were obtained from Gregor et al (2013).

At the pixel level, the greatest uncertainty reduction achieved by the inversion of between 70 to 80% was made to the natural fluxes located near the Cape Town central business district and to fluxes from pixels located closest to the Robben Island measurement site.

Under the current inversion framework, the individual natural and anthropogenic fluxes are less reliably corrected by the inversion compared with the aggregation of these two fluxes. Under the prior flux estimates, the domain of the inversion over the measurement period from March 2012 until June 2013 was estimated to be a large sink of CO₂, but once the inversion was performed, the aggregated posterior flux indicated that it was closer to CO₂ neutral, with an overall uncertainty reduction achieved by the inversion of 25.6%. The results of the inversion indicated that the uptake of CO₂ by vegetation was overestimated by CABLE.

The limitation of the current framework is the large reliance of the inversion solution on the uncertainty estimates of the natural fluxes. By improving estimates of natural fluxes and reducing the uncertainties around these estimates, we can allow the inversion to make better corrections to the fossil fuel fluxes. We are exploring ways to improve the way natural fluxes are specified in the inversion to take advantage of knowledge associated with these fluxes. This is necessary if we wish to use the atmospheric inversion approach for monitoring, reporting and verification (MRV) of CO₂ emissions from a city. For example, if we wish to determine if climate change mitigation efforts are having the desired effect.

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